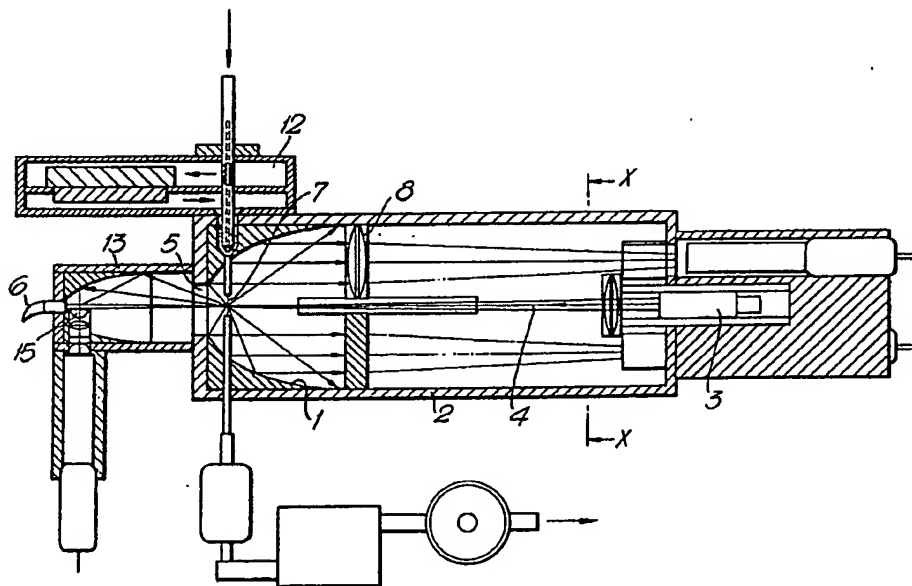


INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁴ : G01N 15/02	A1	(11) International Publication Number: WO 89/04471 (43) International Publication Date: 18 May 1989 (18.05.89)
<p>(21) International Application Number: PCT/GB88/00975</p> <p>(22) International Filing Date: 10 November 1988 (10.11.88)</p> <p>(31) Priority Application Number: 8726304</p> <p>(32) Priority Date: 10 November 1987 (10.11.87)</p> <p>(33) Priority Country: GB</p> <p>(71) Applicant (for all designated States except US): THE SECRETARY OF STATE FOR DEFENCE IN HER BRITANNIC MAJESTY'S GOVERNMENT OF THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND [GB/GB]; Whitehall, London SW1A 2HB (GB).</p> <p>(72) Inventors; and</p> <p>(75) Inventors/Applicants (for US only) : LUDLOW, Ian, Keith [GB/GB]; Parkway Close, Welwyn Garden City, Hertfordshire (GB). KAYE, Paul, Henry [GB/GB]; 1 Coopers Close, Kimpton, Hertfordshire (GB).</p>	<p>(74) Agent: BECKHAM, Robert, William; Ministry of Defence, Procurement Executive, Patents 1A(4), Room 2014, Empress State Building, Lillie Road, London SW6 1TR (GB).</p> <p>(81) Designated States: AT (European patent), AU, BE (European patent), CH (European patent), DE (European patent), DK, FI, FR (European patent), GB, GB (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), NO, SE (European patent), US.</p> <p>Published With international search report.</p>	

(54) Title: PARTICLE ASYMMETRY ANALYSER



(57) Abstract

An apparatus and method which provides a measure of the asymmetry as well as the size of individual fluid borne particles. Laser-light scattering techniques are employed to obtain data on the particles, which is then compared to data on known particle shapes to ascribe an asymmetry factor to the particles.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FR	France	ML	Mali
AU	Australia	GA	Gabon	MR	Mauritania
BB	Barbados	GB	United Kingdom	MW	Malawi
BE	Belgium	HU	Hungary	NL	Netherlands
BG	Bulgaria	IT	Italy	NO	Norway
BJ	Benin	JP	Japan	RO	Romania
BR	Brazil	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	LI	Liechtenstein	SN	Senegal
CH	Switzerland	LK	Sri Lanka	SU	Soviet Union
CM	Cameroon	LU	Luxembourg	TD	Chad
DE	Germany, Federal Republic of	MC	Monaco	TG	Togo
DK	Denmark	MG	Madagascar	US	United States of America
FI	Finland				

PARTICLE ASYMMETRY ANALYSER

This invention relates to the techniques for the analysis of fluid-borne particles and particularly for looking at the asymmetry of such particles. For example, in the study of aerosols, aerosol dispersions and airborne particulate pollution control, there is a requirement for the rapid determination of particle size distribution especially in the diameter range 1 to 10 microns, together with some knowledge of the geometry and symmetry of individual particles. The latter information could, for example, enable particles with spherical symmetry to be identified and thus allow the counting/monitoring of liquid droplets in an environment including other solid, non-spherical particles. In the context of the present specification, the term particles is intended to apply both to solid bodies and to drops of liquid.

It is desirable for such techniques to be able to count individual particles in a sample at rates of, typically, 20,000 particles per second, to be able to distinguish between spherical and non-spherical particles in the sample and to count each type. Another desirable feature is to categorise spherical particles having diameters of 0.5 - 15 microns into a number of size bands and also in this connection to classify particle coincidences as 'non-spherical' and hence to ignore them in the compilation of size spectra.

The normal techniques for the examination of particles, as used in several instruments available commercially, employ the detection and analysis of electromagnetic radiation scattered by the particles. All such instruments use a mechanical mechanism to drive the sample air through a "sensing volume" where the carried particles are illuminated by the incident electromagnetic radiation. The radiation scattered by the particles is received by one or more detectors which convert the energy to electrical signals from which information may be extracted by appropriate electrical circuits.

One class of instrument available commercially permits the collection of scattered radiation from large numbers of particles simultaneously, and uses this information to determine a mean figure for particulate mass per unit volume of gas or air, or the statistically averaged size distribution of particulate matter. These instruments are not capable of examining individual particles, and therefore cannot yield accurate particle counts or information relating to particle morphology.

A second class of instrument uses the properties of laminar flow in gases to restrict the particles to a smaller sensing volume and then, by focusing the incident electro-magnetic radiation in some way, is capable of the examination of individual particles, yielding a particle count and possibly approximate size distribution.

The prior art instruments, therefore, will give, to a certain extent, information on particle size and particle count. However, there is no instrument available that is capable of giving information on the asymmetry of individual fluidborne particles.

There is therefore a need for a particle analyser which can analyse individual fluid-borne particles and give information as to the asymmetry of the particles by, for example, ascribing an asymmetry factor to the individual particles.

According to one aspect of the present invention there is provided a particle analyser which comprises means for delivering a sample of fluid in the form of a laminar flow fluid, means for illuminating the sample with a beam of radiation, means for reflecting and directing scattered radiation on to light collectors, means for deriving data from the light collectors to describe the particle where the analyser includes means for comparing the data with data on known shapes to determine the degree of particle asymmetry.

The beam of radiation is preferably provided by a laser, and the scattered radiation is reflected by a concave reflector, preferably an ellipsoid mirror which directs the radiation towards radiation collectors. Radiation scattered at low angles is detected in a second chamber, which leads from an aperture in the ellipsoid mirror, by radiation collectors, preferably optical fibres arranged concentrically around the unscattered beam. The radiation collected is then converted into electrical signals, processed and analysed and by comparing with data on known particle shapes the particles are ascribed an asymmetry factor.

Furthermore, in addition to the asymmetry factor the size of the particle may also be determined. A large number of particles may be ascribed an asymmetry factor, and the cumulative results of this operation coupled with the associated size spectra, could be used to generate a topographical 'thumb print' of the particles in an environment which may be of more value than the data of single particles taken alone.

In looking for sphericity, the criterion for classification for spherical particles can be defined readily as symmetrical scattering about the axis of the illuminating beam of randomly polarised or circularly polarised radiation. Therefore a number of radiation
5 collectors are placed radially symmetrically about the reflection axis of the concave reflector.

In looking for the degree of asymmetry, the arrangement of the collectors could not be assumed to be the optimum for particle asymmetry analysis. The design of the scatter chamber must allow for
10 the flexibility of collector configurations specifically required, and the positions of which to be varied at will.

The advantage of this technique is that, by using optical fibre collection optics, one can readily simulate the effect of placing almost any number of collectors at any position around most of the scattering
15 sphere, a task which would otherwise be mechanically extremely difficult. Thus with a high degree of flexibility, various detection geometries may be tested without the need for mechanical changes to the chamber itself.

According to a second aspect of the present invention a method
20 of determining the asymmetry of fluid-borne particles includes the steps of:-

providing a sample of fluid in the form of a laminar flow;
illuminating the sample with a beam of radiation;
reflecting the radiation scattered by individual particles to
25 radiation collectors;
deriving data from the light collectors describing the particle;
and
comparing the data with data on known shapes to determine the
degree of particle asymmetry.

30 The sample may be an aerosol.

Two embodiments of the invention will now be described by way of example only and with reference to the accompany drawings of which:

Figure 1 is a schematic side view in section of a particle analyser for analysing spherical particles.

35 Figure 2 is a sectional view of the analyser in Figure 1 along the line x-x
Figure 3 is a schematic side view in section of an asymmetry analysis system.

Figure 1 illustrates a basic form of the invention where only spherical particles are analysed in which a parabolic concave reflector (1) is located at one end of a scatter chamber (2). Mounted at the other end of the scatter chamber (2) and aligned with the principal axis of the reflector (1) is a laser (3), which directs a beam of radiation (4) towards a hole (5) in the reflector (1) and chamber (2) at the principal axis of the reflector. After passing through the hole (5) the beam (4) enters a beam dump (6), typically a Rayleigh horn.

A sample (7) of laminar flow air is directed into the chamber (2) to intercept at right angles the laser beam (4) at the focal point of the parabolic reflector (1).

A particle in the sample (7) will deflect the radiation out of the beam (4) onto the reflector (1) which reflects it parallel to the principal axis to radiation collectors (8) adjacent the laser (3). The radiation collectors (8) may be photo multiplier units, optical fibres leading to such units, or lenses for directing the light onto fibres or units.

As shown in Fig 2 three radiation collectors 8 are arranged radially around the beam 4. In such an arrangement symmetrical scattering can be directed which will identify spherical particles. Indeed, any number of radiation collectors 8 may be arranged radially about the beam of radiation 4.

Figure 3 shows a preferred embodiment of a particle analyser according to the present invention which is able to analyse individual particles and ascribe to them an asymmetry factor. In this embodiment, the laser (3) is mounted beneath the chamber (2) and at 90° to principal axis of the reflector (1). The beam (4) being reflected onto the principal axis of the reflector by a prism or mirror (9) suitably positioned on the axis. Indeed, the laser (3) may be mounted just about anywhere about the scatter chamber (2) with a appropriately angled mirror (9) on the axis.

Figure 3 also illustrates the scatter chamber (2) having an ellipsoid reflector (10) with the point of interception between the beam (4) and the sample (7) being one focal point of the ellipse and a collector lens (11) mounted near the second focal point to render parallel the reflected radiation to radiation collectors (8) at the end of the chamber (2). At this point the intensity distribution

represents a spatially modified replica of that scattered into approximately 0.84 of a sphere by the particle. Figure one illustrates the sample (7) of fluid being delivered in laminar flow, by means of a sheath air intake (12) supplying a layer of air at a constant velocity.

5 A certain amount of difficulty is experienced in capturing and analysing the radiation scattered at low angles to the beam (4) direction. At very low angles (1° to 3°) they are swamped by light scattering from laser focussing optics. To overcome this a second scattering chamber (13) is introduced coaxial to the principal axis of
10 the concave reflector (1) on the main scatter chamber (2). Radiation collectors (8) are suitably placed in this chamber to collect the low angle deflections.

Figure 3 therefore illustrates a second chamber (13) in which optical fibres (14) are arranged around the beam (4). The optical
15 fibres (14) may be arranged in concentric rings around the beam (4). The fibres (14) act as radiation collectors for converting the radiation collected into electrical signals for processing and analysis.

As illustrated in Figure 1, the second chamber (13) may alternatively have a second concave reflector (14), which would normally
20 be ellipsoidal, having the point of intersection of the beam (4) and the sample (7) as its second or distal focal point and having a radiation collector (15) at its first or proximal focal point. Thus radiation deflected at low angles will strike the ellipsoidal reflector and be directed onto the radiation collector (15).

25 The radiation collector (15) may be positioned to face the aperture (5) on the first chamber or may be positioned at 90° to this direction as shown in Figure 1. The latter arrangement would collect relatively more radiation of low angle of deflection, but less overall since only deflections in the direction of the face of the collector
30 will be recorded.

Figure 1 illustrates how in use the sample (7) is supplied in laminar flow by means of a sheath of constant velocity filtered air being supplied around the sample. Thus the outer parts of the sample
35 flow at the same velocity as the inner parts. The outer parts of the sample would otherwise flow more slowly due to friction with the stationary air next to the sample flow. Additionally, and more importantly the coaxial tube supplying the sheath of air is designed

to dynamically focus the particles in the sample to provide a laminar flow of particles. Thus making it easier to line up the particle flow on the focal point of the reflector.

The asymmetry particle analyser operates as follows. The laser beam, produced by a gas laser, enters the chamber at right angles to the reflector axis and is reflected through 90° along the principal axis of the reflector. The radiation scattered by individual particles from approximately 19° to 145° relative to the beam axis is thus reflected onto the aspheric collection lens at the rear of the chamber. This lens renders the emerging light parallel, and the intensity distribution across this output window represents a spatially modified replica of that scattered into approximately 0.84 of a sphere by the particle.

With the collected light in the form described above, the positions of the optical fibre detectors to measure the light distribution may be varied at will.

To determine particle sphericity the detectors would be placed symmetrically about the axis of the output window.

In this way, with the use of optical fibre optics, one can readily simulate the effect of placing almost any number of detectors at any position around most of the whole scattering sphere.

Based upon the results of theoretical models and experimental results of scattering patterns of known shapes, algorithms are used to ascribe to particles an asymmetry factor.

The processing of data from particles to determine their asymmetry could be handled by a transputer as produced for example by the British Inmos chip manufacturers.

One transputer is used for each detection channel. In this way, tasks hitherto performed serially on incoming data from channels could be performed on all channels simultaneously giving a substantial increase in data throughput.

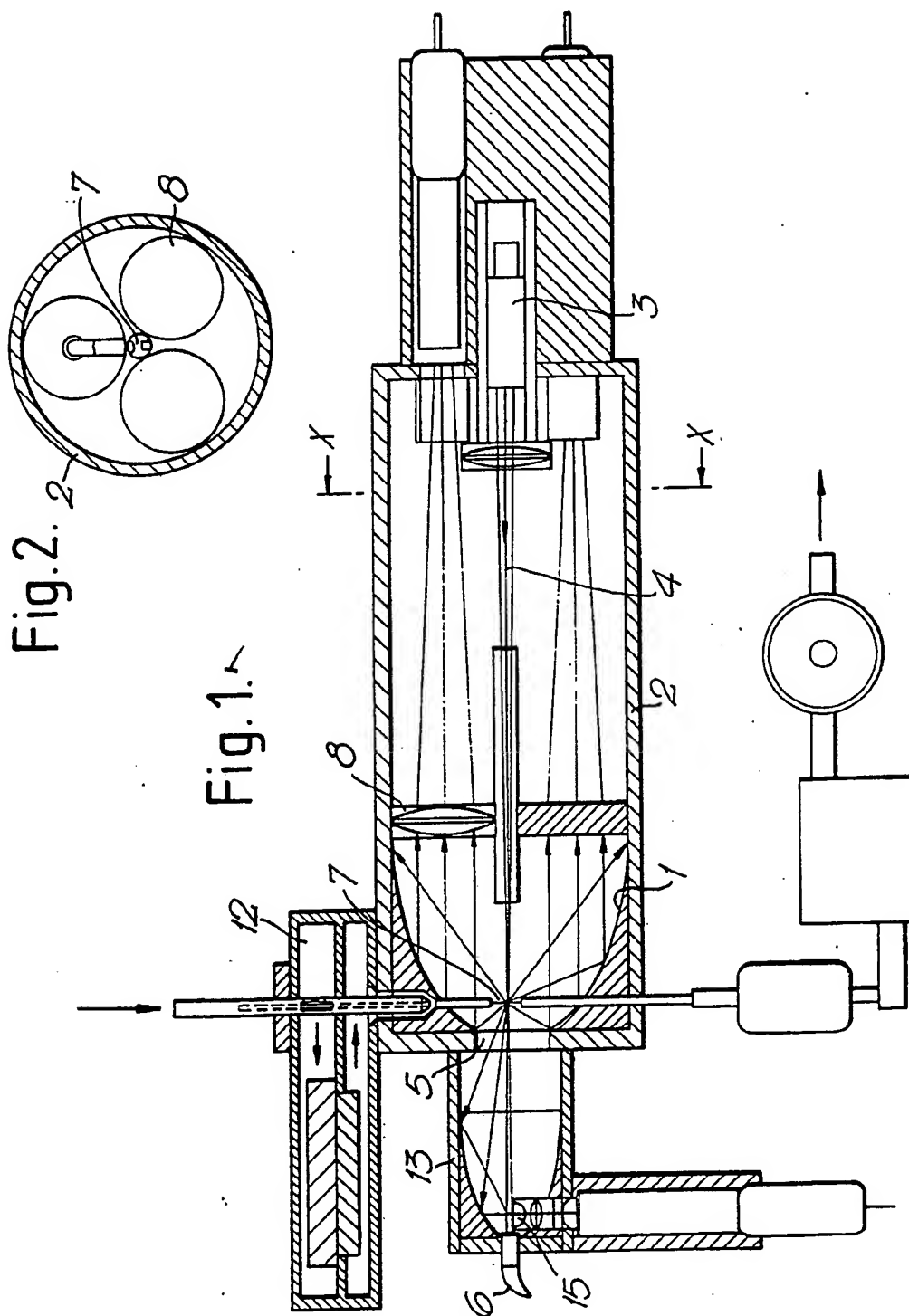
Although this invention has been described by way of example and with reference to possible embodiments thereof, it is to be understood that modifications or improvements may be made without departing from the scope of the invention as defined in the appended claims.

CLAIMS

1. A particle analyser including:
means for providing a sample of fluid in the form of a laminar flow;
means for illuminating the sample with a beam of radiation;
means for directing the radiation scattered by individual particles towards radiation collectors;
means for deriving data from the radiation collectors to describe the particle; wherein the analyser also includes
means for comparing the data with data or known shapes to determine the degree of particle asymmetry.
2. A particle analyser as claimed in Claim 1 wherein the illuminating beam is provided by a laser.
3. A particle analyser as claimed in Claim 1 or Claim 2 wherein the means for directing the radiation is a concave reflector.
4. A particle analyser as claimed in Claim 3 wherein the concave reflector is an ellipsoid reflector.
5. A particle analyser as claimed in any previous claim wherein the radiation collectors are optical fibres leading to photomultipliers.
6. A particle analyser as claimed in any previous Claim wherein the radiation collectors may take any configuration and their positions may be varied at will.
7. A method in determining the asymmetry of fluid borne particles including the steps of:-
providing a sample of fluid in the form of a laminar flow;
illuminating the sample with a beam of radiation;
reflecting the radiation scattered by individual particles to radiation collectors;
deriving from the collectors data describing the particle; and
comparing the data with data on known shapes to determine the degree of particle asymmetry.
8. A method as claimed in Claim 7 where the fluid is an aerosol.
9. A method as claimed in Claim 7 or Claim 8 wherein the illuminating beam is provided by a laser.

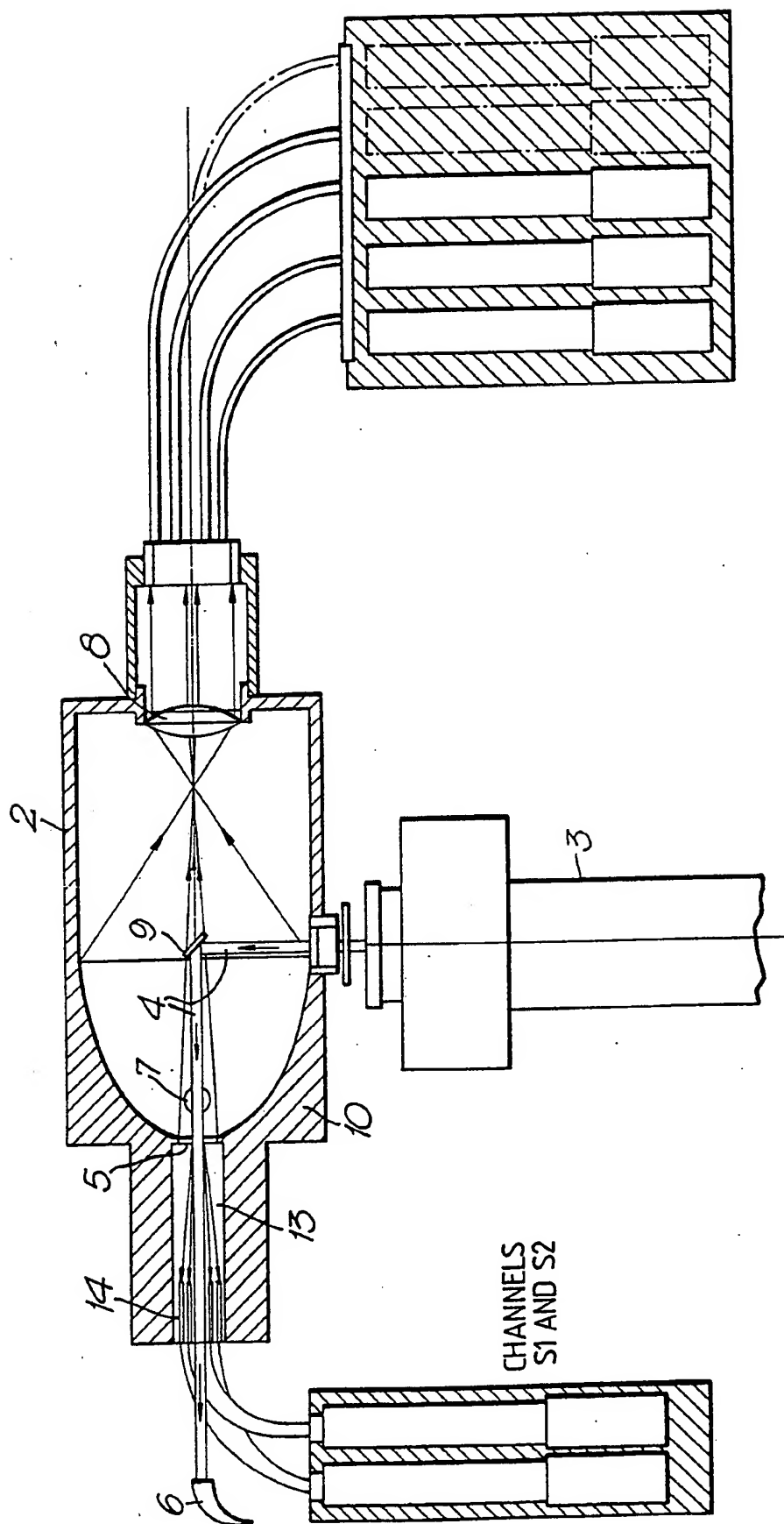
10. A method as claimed in any one of Claims 7 to 9 wherein the radiation scattered by individual particles is reflected by a concave reflector towards the light collectors.
11. A method as claimed in Claim 10 wherein the concave reflector has an ellipsoid interior surface.
12. A method as claimed in any one of Claims 7 to 11 wherein the radiation collectors are optical fibres connected to photomultipliers.
13. A particle analyser substantially as herein described with reference to the accompanying drawings.

1/2



2/2

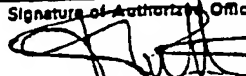
Fig.3.



INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 88/00975

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) *		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC ⁴ : G 01 N 15/02		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System ¹	Classification Symbols	
IPC ⁴	G 01 N 15/02; G 01 N 15/14	
Documentation Searched other than Minimum Documentation to the extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ⁶	Citation of Document, ¹¹ with Indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 4606636 (J. MONIN et al.) 19 August 1986 see column 2, lines 28-68, column 3; column 4, lines 1-65 --	1-7,9-12
X	K.R. Spurny: "Physical and Chemical Characterization of Individual Airborne Particles", 1986, (Chichester, Ellis Horwood, GB), J. Allen: "Size and shape measurement of individual aerosol particles by asymmetric laser light scattering", pages 101-115 see pages 102-103, paragraph 6.2; pages 105-107, paragraphs 6.5-6.7 --	1,2,7-9
A	GB, A, 2041516 (COULTER ELECTRONICS) 10 September 1980 see page 5, lines 123-130; page 6; page 7, lines 1-89; figures 1,3,4 --	1,3,4,10, 11
A	FR, A, 2535051 (UNIVERSITE DE SAINT ETIENNE) 27 April 1984 ./.	1,5,10,12
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>* Special categories of cited documents: ¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"A" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
8th February 1989		- 1. 03. 89
International Searching Authority		Signature of Authorizing Officer
EUROPEAN PATENT OFFICE		 P.C.G. VAN DER PUTTEN

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
	see page 6, lines 19-37; page 7; page 8, lines 1-27 -----	

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.**

GB 8800975

SA 25163

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 23/02/89. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4606636	19-08-86	None	
GB-A- 2041516	10-09-80	GB-A, B 2042166	17-09-80
		FR-A, B 2445960	01-08-80
		FR-A- 2445961	01-08-80
		FR-A, B 2445962	01-08-80
		DE-A- 3000032	31-07-80
		DE-A- 3000033	31-07-80
		DE-A- 3000034	31-07-80
		GB-A, B 2044445	15-10-80
		JP-A- 55112548	30-08-80
		JP-A- 55124028	24-09-80
		US-A- 4341471	27-07-82
		CA-A- 1135971	23-11-82
		CA-A- 1136883	07-12-82
		CA-A- 1141193	15-02-83
		US-A- 4523841	18-06-85
		US-A- 4273443	16-06-81
FR-A- 2535051	27-04-84	DE-A- 3338364	17-05-84
		JP-A- 59150325	28-08-84